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Fuzzy quality analysis of web services implemented in virtualised environment

Keywords

virtualization, web service, quality, availability, state-transitional model, fuzzy number

Abstract

The paper describes the quality analysis of web services implemented in virtualised environment. It takes into account the reliability and performance aspects of software and hardware elements of the web service. The presented state-transitional model considers the reconfiguration process to maintain the continuity of business services. The reconfiguration is based in on the redeployment of virtual machines so for some time the system operates in a degraded state. Author propose two quality measures based on the web service availability and maximum handled requests calculated at each of degradation levels. Moreover, authors proposed to model the web service reliability parameters by fuzzy numbers. A method for calculating fuzzy membership functions of quality measures are also presented.

1. Introduction

IT industry is nowadays affected by virtualization trend. Increasing popularity of virtualization was born since it became clear that virtualization is supposed to help companies save money on IT costs [9]. Such features as the backups and rollback allows to recover recovering virtual machine after security breaches [6]. In virtualization environment operating systems are independent from the hardware so they can be easily moved to another server [8]. This allows to improve reliability of the systems by moving affected by failure system or software components to other hosts. This process is called reconfiguration [12].

When a fault occurs in the system, for some time it operates in a degraded state or becomes inoperational in a failure state until maintenance procedures start. It is based on partly restoring the system operability by redeployment of virtual machines so for some time the system operates in degraded state and finally is restored to full operability. The performance of the web service is different at each level of degradation [11].

One of the most significant problems that web systems providers have to face is how they can provide the QoS (quality-of-service). Therefore, there is a need to assess the quality of the web service. Since the Web based systems are clearly renewable, therefore the standard measure of availability is often used. However, it does not reflect the comfort of using the services by the end-users, especially connected with operation in the degraded state. The comfort of using the service could be measured by its response time [10]. It has been proven in [7] that if user will not receive answer for the service in less than 10 seconds he/she will probably resign from active interaction with the service and will be distracted by other ones. The response time in web systems depends not only on the system software and hardware structure (in our analysis defined by the degradation level), but also on the intensity of user request [4]. Therefore, we propose to measure the quality of the web service by a set of pairs: the steady-state probability that the system is operating at the given level of degradation and the maximum number requests for which the response is achieved in time less than 10 s. Chapter 2 describes a method of calculating such defined quality by a usage of the state models and Markov chains.

The estimation of steady-state probabilities requires a knowledge of the system reliability parameters (intensity of failures, reconfiguration and repairs). Due to ongoing changes in web systems structure it is hard to have enough number of real data values to estimate intensities. The possible solution is to set the parameters based on experts' experience and to

operate with them based on the fuzzy numbers [3], [13]-[14]. Such approach is presented in chapter 3.
Finally, in chapter 4, we propose how to assess the functional quality defined as the expected value of the web service availability for each of degradation levels. The availability of the web service is defined as the probability that a user will be served within a time limit at a given degradation level and under given intensity of the user requests. We also apply here the fuzzy number analysis to deal with the problem of reliability parameters inaccuracy.

2. Quality analysis

2.1. Introduction

There are different causes of faults in web systems. Hardware faults, most commonly considered in reliability analysis, occur relatively rare. Most failures are caused by exploitation of software faults or by human mistakes. Regardless the origin, failures can be analysed in similar way since they result in decrease of web service performance or in a complete blockage [12]. Faults occur in the system randomly, usually with a predictable distribution. Then the web service for some time operates in a degraded state or becomes inoperational in a failure state, until maintenance procedures restore it to full operability [11]. Therefore, under additional assumptions considering the nature of stochastic process, we can estimate the steady state probability of a given degradation level.

2.2. Quality measure

As it was stated in the introduction, we propose to describe the quality of the web service by a set of pairs:

$$\left(P(l), q_l\right) \text{ for } l = 0..L \,, \tag{1}$$

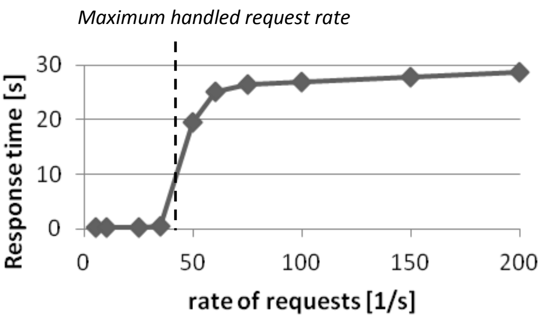

Figure 1. Response time characteristic of a web service

where l is an identification of degradation level, $P(l)$ is a steady state probability that the web service is at the l-the degradation level, q_l is the maximum properly handled request rate. It is set based on the web service response time characteristic as presented in *Figure 1*.

2.3. State-transitional model

We propose to analyse the system based on a stochastic state-transition process, in which the states are described by the vectors of operability states of all the virtual machines in the system. Assuming that the faults can either have no effect on specific virtual machine or can cause them to become fully unavailable, the system reliability state is defined as the vector of the up-down states of the virtual machines. The transitions between states are caused by incident occurrence and by renewal.
The state-transition model (S-T) can be analysed using a number of approaches: as a Markov chains, using semi-Markov processes or using Monte Carlo simulation.
Whatever the method used for analysing the S-T model, the results are the probabilities that the system is in a specific reliability state at a time instance or the steady-state probabilities.
When considering the quality of web services that can operate in degraded states, each of reliability states has to be classified to one levels of degradation, not just as up or down as its done in classical reliability analysis. We could describe each level of degradation by its probability summing of probabilities of reliability states assigned to a given degradation level.
Let us assume a web service deployed in virtual environment consisting of two servers. We propose to analyses following reliability states of the system:

- normal operation (S_0)
- hardware failure (S_1) – the hardware failure results in system inoperation, it occurs with intensity: λ_H ; after the failure reconfiguration is performed (with intensity δ), and for some time (till component replacement with intensity μ_H) the system is working in degraded state (S_5);
- failure of software resulting in system inoperation (S_3) – with failure intensities λ_{S1} and intensities of repair: δ
- failure of software resulting in system performance degradation (S_2) – with failure intensitie: λ_{S2} and intensitie of repair: δ
- power down (S_4) – modern system has UPS but they have a limited capacity so there is a probability that a cut off of electricity will cause the system down; the intensity of power downs

is marked by λ_P, the repair intensity is marked by μ_P.

It results in S-T model presented in *Figure 2*.

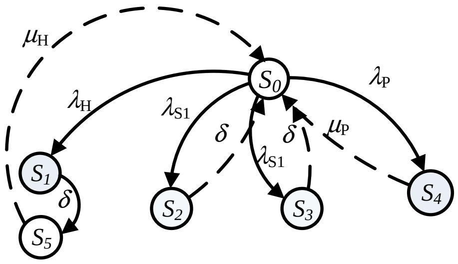

Figure 2. The S-T model of exemplar web service

In the presented model we have not consider states with two or more failures. Such assumption simplifies graph presented in *Figure 2*. Moreover repair times for real web systems are very short compared with times to failure therefore probabilities of states modelling co-occurrence of independent failures is very small. Therefore they are not considered.

2.4. Markov analysis

Assuming that state transitions are described by exponential distributions *Figure 2* describes the Markov process. Therefore, the steady state probabilities $Pr(S_i)$ can be determined solving linear equations [1] with following transition matrix:

$$\Lambda^T = \begin{bmatrix} -\begin{pmatrix}\lambda_H + \lambda_{S1} \\ + \lambda_{S2} + \lambda_P\end{pmatrix} & 0 & \delta & \delta & \mu_H & \mu_P \\ \lambda_H & -\delta & 0 & 0 & 0 & 0 \\ \lambda_{S1} & 0 & -\delta & 0 & 0 & 0 \\ \lambda_{S2} & 0 & 0 & -\delta & 0 & 0 \\ \lambda_P & 0 & 0 & 0 & -\mu_H & 0 \\ 0 & \partial & 0 & 0 & 0 & -\mu_P \end{bmatrix}$$

We have distinguished four degradations levels. Following assumed relations to the system states, the steady state probabilities of each of degradation level could be calculated as follows:

$$P(0) = \Pr(S_0)$$
$$P(1) = \Pr(S_2)$$
$$P(2) = \Pr(S_5)$$
$$P(3) = \Pr(S_1) + \Pr(S_3) + \Pr(S_4)$$

2.5. Experimental results

Assuming following values of reliability parameters:

- hardware failure intensity
  λ_H = 2 failures per year,
- software failure intensity
  $\lambda_{S1}, \lambda_{S2}$ = four failures per year,
- power failure intensity
  λ_P = one failure per year,
- failure discovery and reconfiguration intensity
  δ = one per 14 h,
- hardware repair intensity
  μ_H = one per 18 h,
- power down repair intensity
  μ_P = one per 4 h,

the values of steady state probability of each degradation levels are presented in *Table 1* in 2nd column.
Due to the fact that virtualized environment allows simple modification of the system configuration, we have performed load tests on the real system for all analysed degradation levels. The measured maximum handled request rates are presented in *Table 1* in column 2.

Table 1. Quality measures for exemplar web service

Degradation level	Probability of degradation level	Quality coefficient (maximum handled request rate)
0	0.98115	121
1	0.00636	83
2	0.00091	72
3	0.01158	0

2.6. Semi-Markov analysis

Other method used to calculate the steady state probabilities of S-T models are Semi-Markov processes [5]. They have a Markov chain and a renewal process embedded within its structure [2]. To apply positive recurrent, irreducible, and aperiodic semi-Markov process for calculating steady state probabilities we need to define the vector of average duration of states and the transition probabilities matrix.
Considering the S-T model from *Figure 2* and the fact that there are only single way transitions from all other states then S_0, when we assume the exponential distributions of transition times from state S_0 (times connected with failures) the achieved results for Semi-Markov process will be identical to Markov one. Therefore, the results presented in 2.3 and 2.4 could be extended to a wider group of processes. Repair and reconfiguration times could be driven by any distribution with a known and limited average value.

3. Fuzzy approach

3.1. Introduction

The calculation of probability of degradation levels described in the previous chapter requires a knowledge of reliability parameters, i.e. intensities of four kinds of failures: λ_H, $\lambda_{S1}, \lambda_{S2}$ and λ_P, as well as intensities of repair times: μ_H, μ_P and reconfiguration time: δ. Due to a fact that failures occurs very rare for modern web systems, as well as a fact that each web system is different in software architecture, used hardware and all time changing methods of attacks it is hard to establish these parameters by statistical methods. Therefore, the reliability parameters are in real case analysis are fixed based on experts' experience. That's why we propose to use fuzzy approach to reliability parameters descriptions.

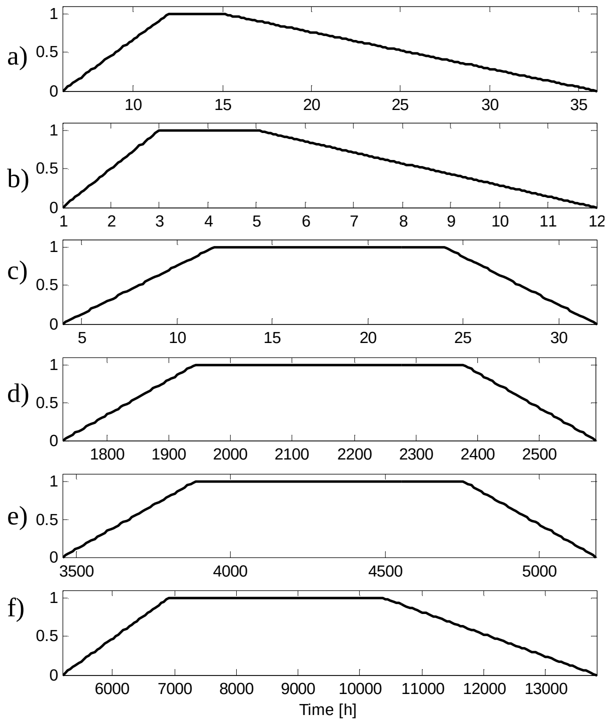

Figure 3. Mean values membership functions of a) failure discovery and reconfiguration time, b) power down repair time c) component replace time d) time to software failure (of 1st and 2nd type), e) hardware failure f) time to power failure

3.2. Fuzzy reliability parameters

There is a large number of different fuzzy membership functions. We propose to use a simple, but intuitive Π-shape ones. It is defined by four parameters *a*, *b*, *c* and *d* : $A(a,b,c,d)$, with membership function given by:

$$\mu_A(x) = \begin{cases} 0 & x \le a \\ \frac{x-a}{b-a} & a < x < b \\ 1 & b \le x \le c \\ \frac{d-x}{d-c} & c < x < d \\ 0 & d \le x \end{cases}$$

In our opinion the mean values are more intuitive for experts then the intensities. That's why we propose to use fuzzy representation of mean values then the intensities. The values of used in numerical experiments fuzzy values of reliability parameters are presented in *Figure 3*. They corresponds to crisp values used in calculation presented in chapter 2.

3.3. Fuzzy probability

The method calculation of probability of being in a given degradation level states is given by a function of reliability parameters were presented in chapter 2. Since we are using the fuzzy numbers for representing the mean values the intensities has to be replaced by its inverse: mean value (marked as *r* for failures, *m* for repairs and *d* for reconfiguration). It will give following set of formulas:

$$\begin{aligned} P(1) = {} & (m_H m_P m_{S2} m_{S1}) / (d m_P m_{S2} m_{S1} + r_P m_P m_{S2} m_{S1} \\ & + m_H r_H m_{S2} m_{S1} + m_H d m_P m_{S1} + m_H m_P m_{S2} m_{S1} + m_H d m_P m_{S2}) \\ P(2) = {} & (m_H d m_P m_{S2}) / (d m_P m_{S2} m_{S1} + r_P m_P m_{S2} m_{S1} \\ & + m_H r_H m_{S2} m_{S1} + m_H d m_P m_{S1} + m_H m_P m_{S2} m_{S1} + m_H d m_P m_{S2}) \\ P(3) = {} & (r_P m_P m_{S2} m_{S1}) / (d m_P m_{S2} m_{S1} + r_P m_P m_{S2} m_{S1} \\ & + m_H r_H m_{S2} m_{S1} + m_H d m_P m_{S1} + m_H m_P m_{S2} m_{S1} + m_H d m_P m_{S2}) \\ P(4) = {} & (m_{S1} (d m_P m_{S2} + m_H d m_P + m_H r_H m_{S2})) / (d m_P m_{S2} m_{S1} \\ & + r_P m_P m_{S2} m_{S1} + m_H r_H m_{S2} m_{S1} + m_H d m_P m_{S1} \\ & + m_H m_P m_{S2} m_{S1} + m_H d m_P m_{S2}) \end{aligned} \qquad (1)$$

The membership function of the above probabilities could be defined by the Zadeh's extension principle [14] as :

$$\mu_P(y) = \underset{y=P(x_1,x_2,\ldots,x_7)}{MAX} \{ MIN(\mu_{m_H}(x_1), \ldots, \mu_{m_\delta}(x_7)) \} \qquad (2)$$

The analytical solution of the above formula for general case is not possible. But the formulas for probabilities (1) are in a form of fractions of sums of products of fuzzy numbers of the same type. The procedure of addition or subtraction of fuzzy numbers is simple, but the procedure of multiplication or division is very complex. In [3] authors proposed analytical solution for multiplication of two triangular fuzzy numbers, but in our case we have four fuzzy numbers to be multiplied. And since the product of two fuzzy number of Π-shape is not a of Π-shape method this approach could not be extended to analyzed in analyzed case.

That is why the computer simulation method was used to solve (2). It is based on probing the entire space consisting of *n*-th fuzzy numbers. Assume the each fuzzy number is probed in *m*-th equally spaced points. Let *Y* represents the fuzzy value, and let it be probed in *k*-points. The algorithm is as follows:

For i in size(Y)
  $Y[i]=0$
For $\boldsymbol{x}$ in a set of m^n points
    $y = \Pr(x_1, ..., x_n)$
    $v = MIN(\mu_1(x_1), ..., \mu_1(x_n))$
    i = bean of Y where y falls to
    $Y[i] = MAX(y, Y[i.])$
End

The resulting membership functions of degradation level probabilities for analyzed test case are presented in *Figure 4* by solid line.

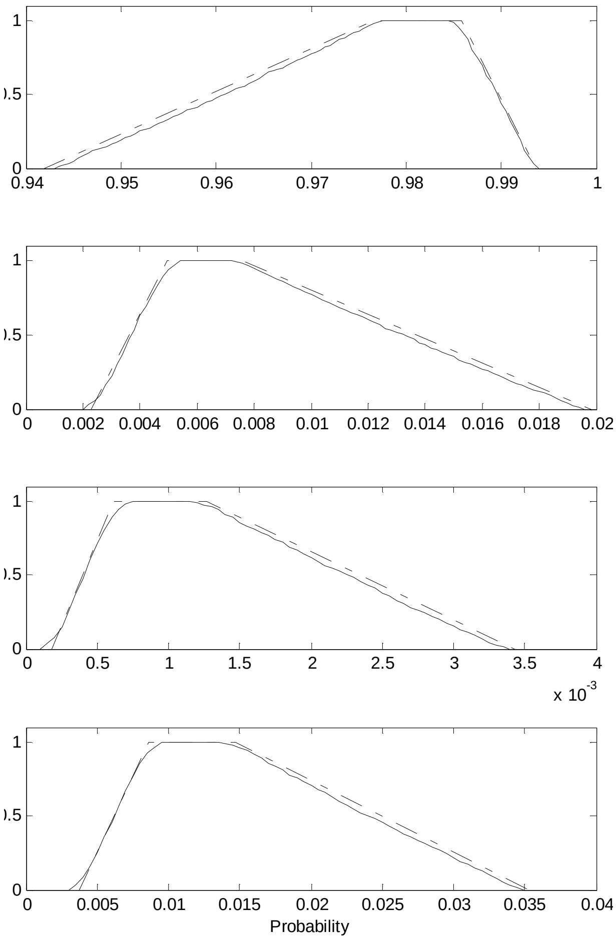

Figure 4. Fuzzy membership function for probabilities(P(0), P(1), P(2) and P(3)) of all analyzed degradation levels

3.2. Simplified approach

The presented above algorithm has a complexity equal to m^7 , so it is a time process. Therefore, we propose to calculate the rough approximation of probability membership function only in characteristic points of trapezoidal fuzzy membership of each of its parameters. For our seven dimensional space, it gives only 4^7 points to be analyzed.

The *b*, *c* parameters of trapezoidal function is selected among points for which fuzzy membership function of each argument is equal to 1, as maximum and minimum value of probability. The *c* and *d* parameter is selected in similar way among left points (i.e. at least one of fuzzy membership function of an argument is equal to 0). It algorithm is as follows:

a=b= +∞
c=d= -∞
For $\boldsymbol{x}$ in a set of 4^n points
    $y = \Pr(x_1, ..., x_n)$
    $v = MIN(\mu_1(x_1), ..., \mu_1(x_n))$
    if v==0
      a=MIN(a,y)
      d=MAX(d,y)
    else
      b=MIN(b,y)
      c=MAX(c,y)
end

The results (dashed line) is presented in *Figure 4*. As it can be noticed the difference between simplified approach and simulation results of the Zadeh's extension principle are very small. It is caused by the structure of probability functions (1) and used values of reliability parameters. The functions (1) are almost flat in analyzed area.

4. Functional quality

When considering the quality of web services in a given degradation level one can use the functional availability [10] defined as the probability that the user will receive an answer in a time less than a given threshold. Obviously, it is a function of the demand for service and not just a single number. The functional availability for the 0^{th} degradation level (normal operation) of analysed test case is presented in *Figure 5*.

We propose to define the web service functional quality as:

$$Q(\Lambda) = \sum_{l=0}^{L-1} P(l) A(\Lambda, l),$$

where $A(\Lambda, l)$ is the functional availability at the l^{th} degradation level for intensity of users equal to Λ
The achieved results for analyzed test case is presented in *Figure 6*.
Next, we have applied the fuzzy analysis in the similar way as presented in chapter 3. Obtained values of fuzzy membership of functional quality are presented in *Figure 7*.

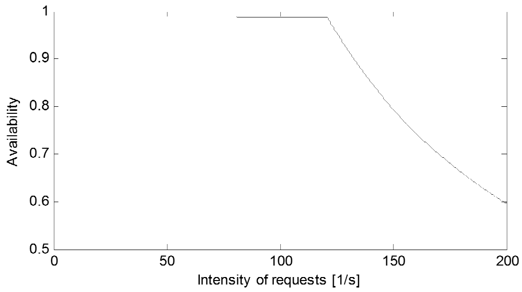

Figure 5. Functional availability of web service in normal operation

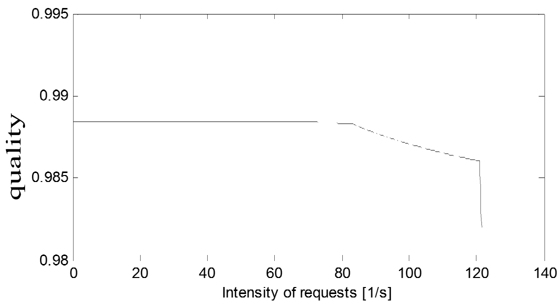

Figure 6. Functional quality of analyzed web service

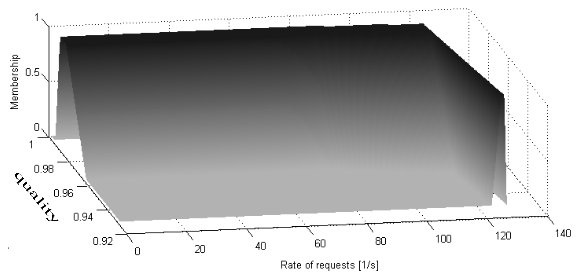

Figure 7. Fuzzy membership of functional quality

5. Summary

Summarizing, we have presented techniques for assessing quality of web services deployed in virtualized environment. Two complementary measures of web service quality were defined. One is based on calculating the degradation level probabilities and corresponding quality coefficient: the maximum number of handled requests. The second is based on calculating the expected value of the web service functional availability. Moreover, the paper introduce the method for dealing with imprecise values of reliability parameters described by a usage of fuzzy numbers. It results in an numerical algorithm that allows to calculate fuzzy membership function for proposed quality measures.

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